RIA Fragmentation Line Beam Dumps

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ENGINEERING

Introduction

– The RIA accelerator has beams of uranium ions impacting fragmentation targets with beam separation in downstream magnets.

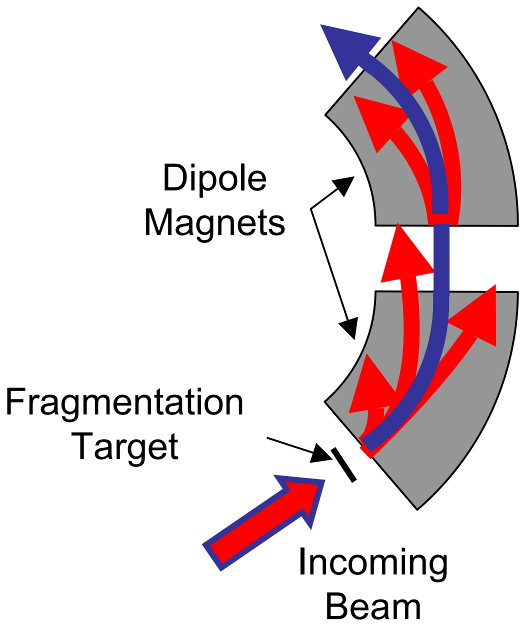
– The high power beam requires a beam dump on each side of the first dipole magnet cavity and a dump downstream of the magnet.

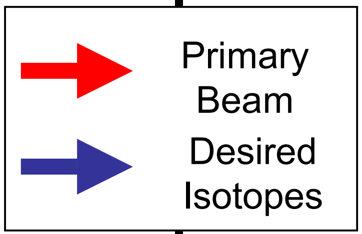
– The dumps absorb 100 kW of power and require a good cooling system to avoid structural and melting problems.

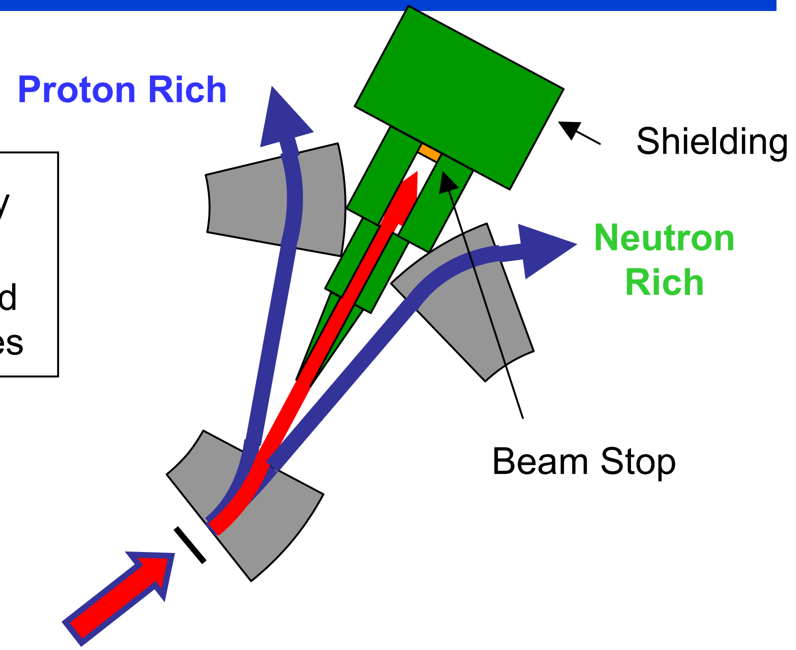
– A dump design is proposed consisting of rotating cylinders with heat removal by water flowing in coolant channels.

– The analysis results show that rotation of the cylinders reduces heat fluxes by a factor of 19 and water temperatures are below boiling.

Possible Beam Trajectories







- Beam stop is challenging
- Shielding against neutrons almost impossible
- Most flexibility in choice of isotope

- Beam stop is easier
- Shielding against neutrons possible
- Possibly some loss in flexibility
- Possibly two users per target

Coolant Options Considered

condition	Air cooling	Water cooling	Liquid metal
stationary	Heat flux too high	Heat flux high. Requires very high h. Water will boil.	Could work. Temperatures and flux high. h is 50 kW/m^{2}K.
rotating	Heat flux is lower. h is too low (0.5 kW/m^{2}K)	Heat flux lower, h is 20 kW/m^{2}K, will work.	Works better than stationary. Temperatures lower.
problems	Won't work. Can not remove heat in either case.	Vacuum seals. Water activation and shielding.	Liquid metal technology difficult.

Thermal radiation may also be viable -

- spread the beam over a thin sheet of metal (C, W,Ta…) (60 x 2 x 0.1 cm)
- thermal radiation from sheet at 2500 ^{o}C will dissipate 100 kW to black body
- attractive as it would mitigate integrated radiation damage effects

Beam Stop Geometry

- The arrangement of the target and fragment separator.
- The beam dump is in the first dipole magnet and consists of two rotating cylinders on each side of the vacuum chamber.

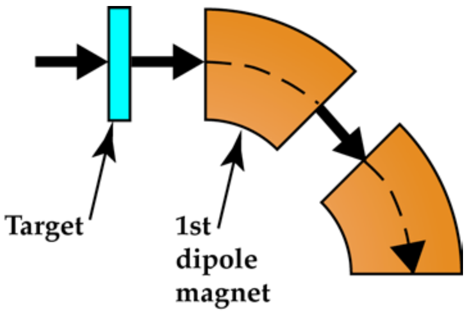


Figure 1. Fragment separator and target schematic.

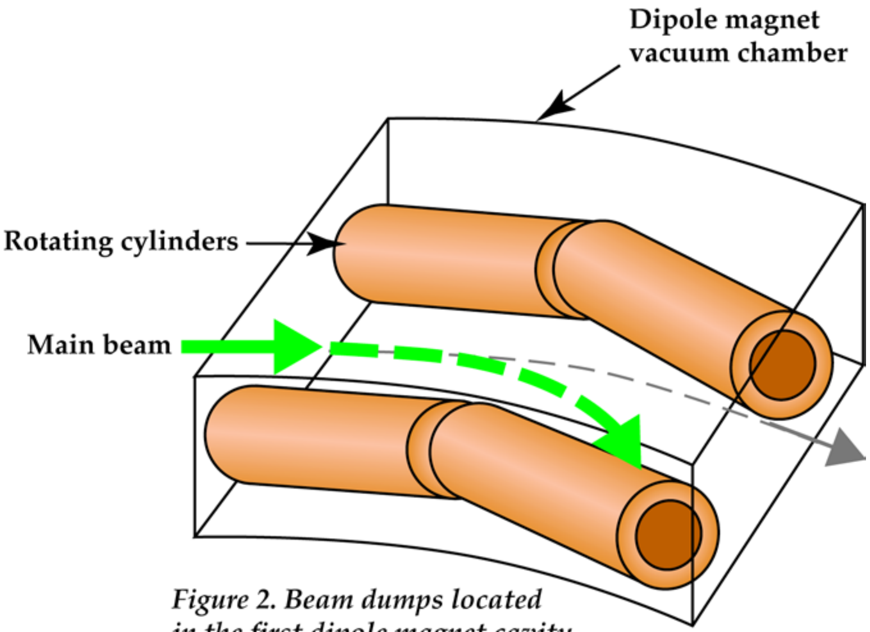
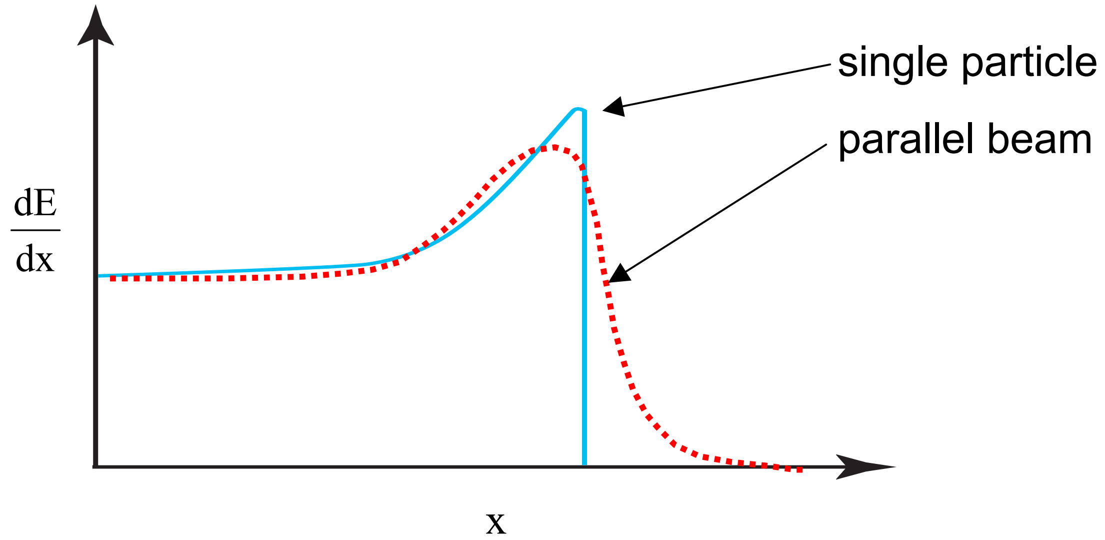


Figure 2. Beam dumps located in the first dipole magnet cavity.

Heavy Ion Energy Deposition in Copper



- The fragmentation line uranium beam diameter is 1 mm with an energy 400 Mev per nucleon.
- In the dipole magnet, the beam has a diameter of 2 cm and impacts the dump at an angle of 15 degrees.
- Energy deposition increases with depth to a depth of 4 mm.

Water Cooled Rotating Cylinders are Used to Spread Beam Energy

- The beam striking the side of the cylinder has a 2 cm. diameter and strikes the cylinder surface at an estimated angle of 15 degrees.

- The copper beam dump cylinders require water cooling with its high convection heat transfer capability at a velocity of 10 m/s and at pressure of 3 atmospheres.

- The cylinders are 12 cm OD, 10.2 cm ID and the channels are 1 mm wide, 2 mm high, and 1 mm apart.

- The cylinders are rotating at nominally 600 RPM . This spreads out the surface heat flux around the whole cylinder and reduces flux by factor of 19.

Heat Transfer Analyses

- The beam power is spread over a 12 cm diameter by 7.5 cm long surface.

- The surface flux is 3.6 MW/m^2 and this power is deposited into the copper over a depth of 1 mm.

- The water cooling at a velocity of 10 m/s has a turbulent convective heat transfer coefficient of 20 kW/m^{2}K.

- The coefficient is calculated from a Nusselt number, Nu, correlation for turbulent water flow with applicable Reynolds, Re, and Prandtl, Pr, numbers:

$$Nu = 0.023\,(Re)^{0.8}\,PR^{1/3}$$

- Inlet water pressure is assumed at 3 atmospheres and the water inlet temperature is 20 C. For 100 kW power, the water heats up less than 6 ^{o}C over its flow length.

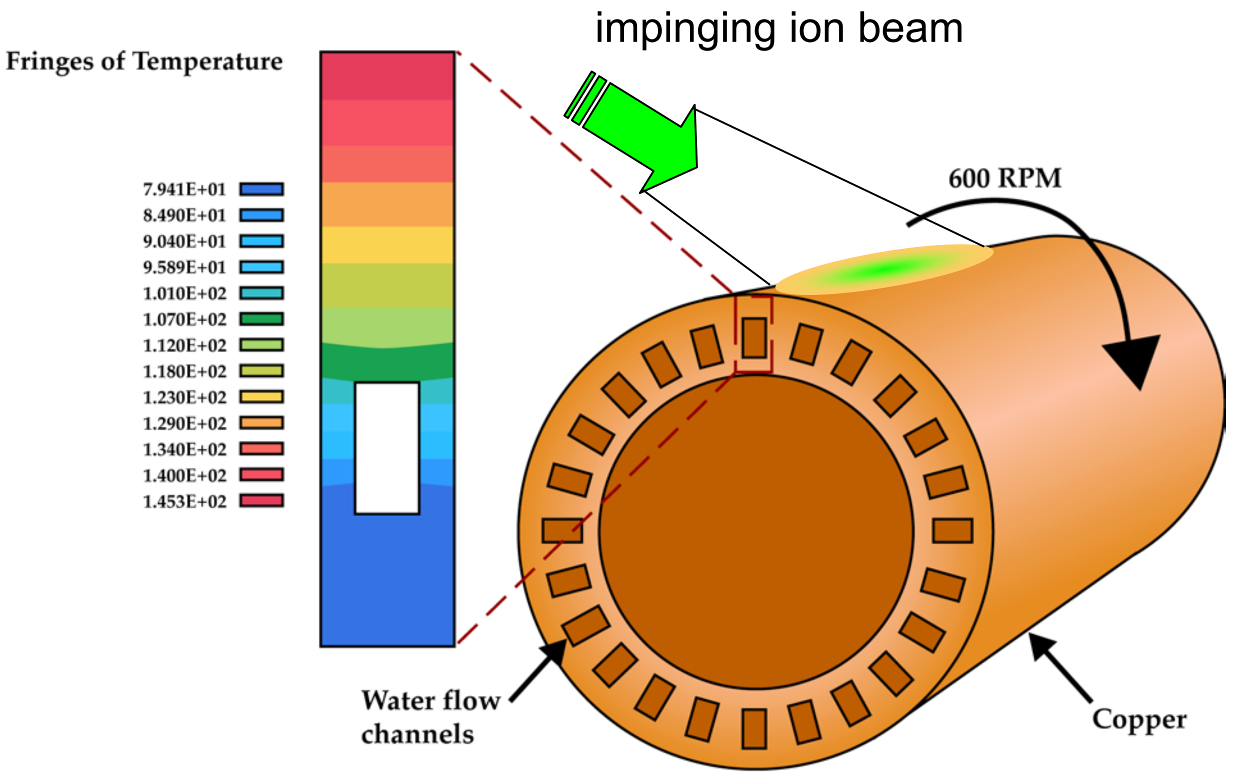
Heat Transfer Analyses (cont.)

- The LLNL heat transfer code TOPAZ2D was used to determine peak copper surface temperatures and channel surface temperatures.

- The code modeled :
  - volumetric energy deposition in the copper;
  - thermal conduction heat transfer in the copper;
  - and the heat transfer in the channels with a convection heat transfer coefficient.

- Analysis indicates that the surface temperature of the copper is relatively low at 145 C and the channel wall temperature is 110 C (well below the water boiling temperature of 133 ^{o}C at 3 atmospheres).

Heat Transfer Analyses (cont.)



Figures 3 and 4. Schematic cross-section of beam dump cylinder design. Calculated temperature profile in a dump cross-section (20 C water).

Future Beam Stop Design Work

- Design a beam dump for the case of the beam not striking the dipole magnet side walls and exiting out of the dipole magnet.

- Analyze the effects of radiation damage on copper structural and thermal properties. Estimate lifetime of material.

- Develop the mechanical design of the manifold system, rotation mechanism, and vacuum seal technology.

- Mitigate the effects of eddy currents set up by the rotation of the cylinders in the magnet fields.

Conclusions

- The spent beam powers on RIA in the fragmentation line need to be taken seriously.

- Thorough Engineering will be necessary to realize a robust, reliable beam stop approach.

- Preliminary work done at LLNL indicates an approach using water-cooled rotating copper cylinders is a reasonable start.

- Additional effort is needed to advance this design and to evaluate other options.